2.2 Fysische oceanografie

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Layers in the ocean

From the surface, the ocean appears to be a uniform mass of water. Through the many scientific studies that have taken place since the *Challenger* expedition, scientists now know that the water in the ocean is anything but uniform. Temperature, salinity and density change with depth, creating layers within the sea.

Density

Density is the mass of an object divided by its volume. The higher the density of an object, the lower it will sit in a container of water. So, when discussing density in seawater, the denser the water is, the lower it will sit in the water column. The least dense water will rise to the surface of the water column and the densest water will sink to the bottom. Two main variables determine the density of water: temperature and salinity.

KEY TERMS

Density: the mass per unit volume of a substance

Thermocline: a boundary between two layers of water with different temperatures

Gradient: the rate of increase or decrease of a characteristic relative to another

Halocline: a layer of water below the mixed surface layer where a rapid change in salinity can be measured as depth increases

Temperature

Temperature is the factor most responsible for changes in density. As temperature increases, density decreases. This is why, when looking at a profile of the water column in the ocean, the warmest water sits on top of the water column. This warm layer is fairly shallow and it sits on top of colder, denser water. Between the two layers is an area where the temperature abruptly changes, known as the **thermocline** (Figure 7.6). Water at the surface may reach 25 °C or higher in tropical seas, but is more likely to be 1 °C at depths of 2000 m or more. In polar seas, the temperature **gradient** is less drastic. In these areas, the surface water is likely to be about 10 °C and cools with depth to about 1 °C, with only a very faint thermocline, if one is present at all.

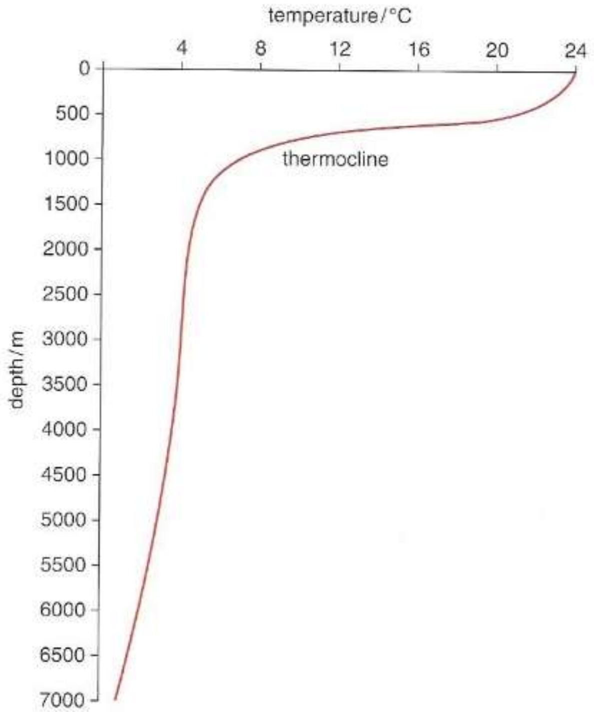


Figure 7.6. Thermocline in a typical tropical sea.

Salinity

Salinity has less of an impact on density than temperature, but the interaction between salinity and temperature makes it worth mentioning. As salinity in the ocean increases, so does the density of the water. Therefore, water with the lowest density floats on top of water with higher densities. This is why in an estuary, fresh water sits above the salt water. Between the less saline, and therefore less dense, surface waters and the more saline, more dense, bottom waters, there is an area where salinity changes significantly with depth. This area is called the **halocline**.

This would indicate that the saltiest water in the ocean is at the seabed. For the most part this is true, but there is one exception: tropical seas. In tropical seas between 30° N and 30° S, the temperatures create high evaporation rates at the surface. This results in a very warm, but also very salty, layer across the surface of the ocean. This layer floats on the surface, in spite of its increased salinity, because the temperature is so high. Just below that layer, the salinity profile shows a steep decrease in salinity, the halocline, until 750 m, followed by a slow increase, as expected (Figure 7.7).

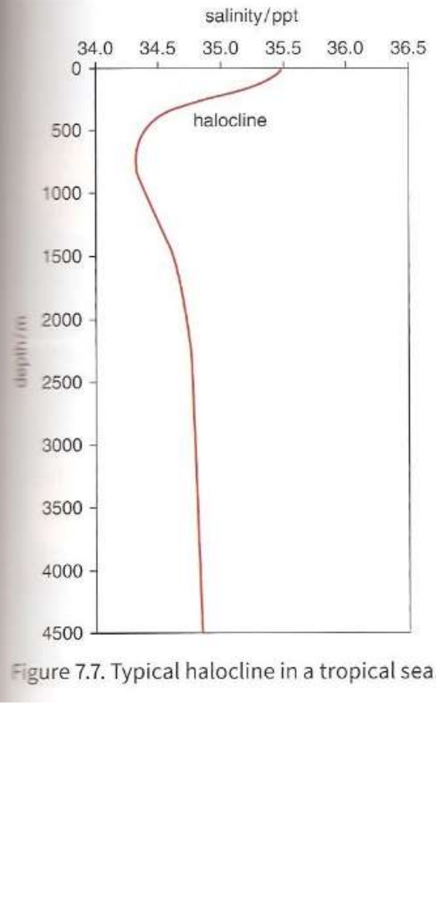


Figure 7.7. Typical halocline in a tropical sea.

Mixing of the layers

The surface layer of the ocean, from zero to 200 m deep, is the best-mixed area of the ocean. As the wind blows across the surface of the ocean, currents and turbulence are created. This water movement mixes the first 200 m of the ocean, making it fairly uniform in both temperature and salinity.

Mixing of the layers within the ocean can also be density driven. For example, if the surface of the ocean cools, the density of the water will increase. As the density increases, the water sinks, carrying with it all the nutrients and dissolved gases that it contained at the surface, mixing with the higher density water that is rising.

SELF-ASSESSMENT QUESTIONS

3 What impact do temperature and salinity have on density?

4 Sketch what you would expect the thermocline to look like in an Arctic environment.

7.3 Physical oceanography

When studying physical oceanography, a scientist must take into account many physical factors that are in fact completely outside the ocean. Physical oceanography involves the gravitational pull of the Moon and Sun, the atmosphere, and the uneven heating of Earth's largely water-based surface. All these pieces of the global environment play a part in the formation of and changes within the marine environment.

Tides

A **tide** is the regular rise and fall of bodies of water as dictated by the gravitational interactions of the Moon, Earth and Sun. Tides can be found in all coastal areas as well as large lakes. Most coastal areas have tides with an interval of 12.5 h, creating two high tides and two low tides each day. Tidal patterns like this are called **semi-diurnal** and the tides are easy to predict. Areas with only one high tide and one low tide each day have a **diurnal** tidal pattern.

KEY TERMS

Tide: the periodic rise and fall of the surface of the ocean resulting from the gravitational pull of the Moon and Sun

Semi-diurnal: occurring twice daily

Diurnal: occurring daily

Tidal range

Tidal range, or tidal amplitude, is the difference in height between the low-water mark and the high-water mark on a coastline (Figure 7.8). Tidal range varies all over the world and from day to day. This variance is due to the gravitational effects of the Moon, Earth and Sun as well as physical features of the coastline where the tide is occurring.

Spring and neap tides

Spring tides create the greatest tidal range for coasts. These tides are not reliant on seasons, but rather on phases of the Moon. Spring tides occur during the phases of new moon (when the Moon is dark) and full moon. So a spring tide can be predicted to happen twice a month.

During spring tides, the Earth, Moon and Sun are in a straight line, with either the Earth between the Sun and Moon or the Sun and Moon on one side of Earth (Figure 7.9). This alignment amplifies the gravitational effects the Moon and Sun have on Earth, creating what is often called a larger than usual ocean bulge. This results in the highest of the high tides and the lowest of the low tides.

Neap tides have the smallest tidal range, with the highest low-tide marks and the lowest high-tide marks. During these tides, the Sun and Moon are at a right angle to each other, with the Earth as the pivot point (Figure 7.9). Neap tides occur during the first- and third-quarter moon phases. During this time the Sun and Moon are pulling the ocean in opposite directions, creating a smaller than average ocean bulge.

KEY TERMS

Tidal range: the difference in height between the high-tide mark and the low-tide mark over the course of a day, also called the tidal amplitude

Spring tide: a tide that occurs when the Sun and Moon are aligned, causing the largest tidal range

Neap tide: a tide that occurs when the Moon and Sun are at right angles from each other, causing the smallest tidal range

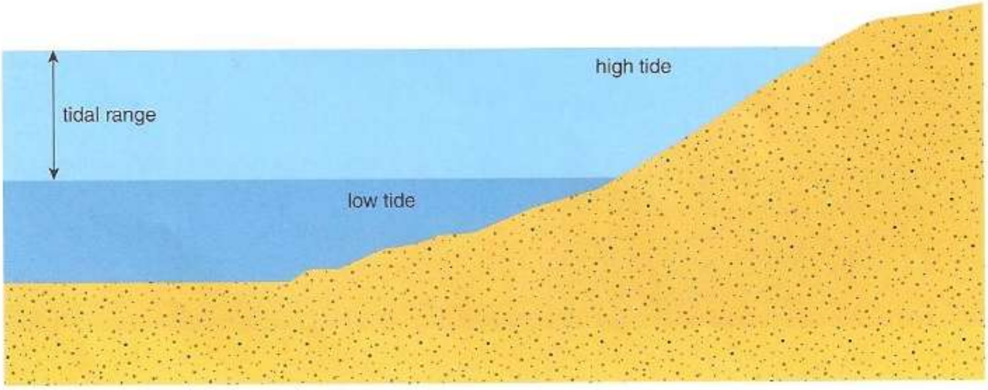


Figure 7.8. How to determine tidal range.

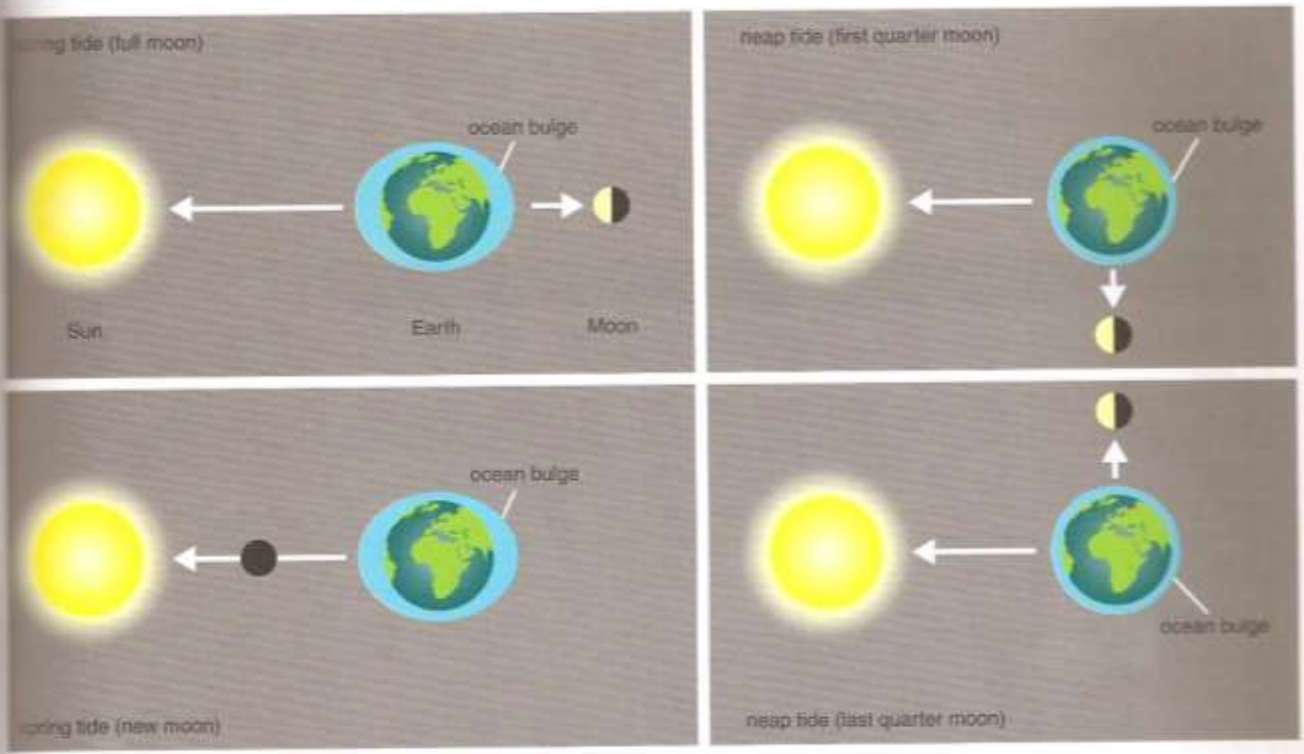


Figure 7.9. Positions of the Sun, Moon and Earth and how that determines the tide.

Physical factors affecting tidal range

Depending on the type of tide, as well as certain physical factors, the tidal range in different parts of the world can vary from 12 m to nearly nothing. The factor with the greatest influence on the tidal range is the coastline itself. The slope of the coast and the size of the body of water it contains, combined with local weather conditions, all influence the tidal range.

The shape of the coastline plays a large role in the size of the tidal range. If the tide is entering a particularly narrow channel (for example a river mouth or entrance to an estuary), the tidal height is increased because the water is being forced into a smaller area. If, however, the tide is happening along an open beach, the tidal height is much smaller because the same volume of water is more spread out.

An extreme example of the coastline changing the tidal amplitude is the Bay of Fundy in Canada, home to the highest tidal range in the world. The average spring tide range here is 14.5 m. The highest water level recorded in the Bay of Fundy, 21.6 m, occurred during the tropical cyclone Saxby Gale in 1869, providing evidence of another physical factor affecting tides: the weather.

Weather is a major factor in tide heights. In particular, changes in wind and air pressure can have incredible effects on tidal range. During a tropical cyclone, air pressure is much lower than usual, allowing water to swell. There are also high winds capable of pushing water onto the shore. Combined, these two factors are capable of creating a **tidal surge**, which is a dangerous rising of water higher than the predicted levels of the tide.

KEY TERM

Tidal surge: the coastal flood or tsunami-like phenomenon of rising water, associated with low pressure weather systems, also called a storm surge

Open ocean, seas and lakes

In the open ocean, tidal ranges are small, approximately 0.6 m. For the most part, the difference between high and low tide is unnoticeable, unless you enter the continental margin, where the water begins to get shallow. Small bodies of water, like the Mediterranean or Red Sea, also have tidal ranges, but they are minimal. Small tidal ranges even occur in large lakes, such as Lake Superior in the northern United States, but the effect is usually masked by the winds blowing across the lake.

KEY TERMS

Current: a continuous physical movement of water caused by wind or density

Coriolis Effect: a force that results from the Earth's rotation that causes objects or particles in motion to deflect to the right in the Northern Hemisphere and to the left in the Southern Hemisphere

Currents

Within any large body of water, you will find **currents**. In the ocean, currents are the continuous movement of seawater in a particular direction. Currents carry with them nutrients, dissolved gases and heat. Organisms can use currents to travel from place to place. Currents are created by different physical forces acting on the water, such as wind, the **Coriolis Effect**, temperature, salinity and tides. There are two major types of currents in our oceans: surface currents and deep-water currents.

Surface currents

Surface currents are typically driven by the wind. These currents are steady and dependable as a result of global wind patterns caused by an uneven heating of the Earth's surface by the Sun. Areas with large amounts of solar radiation (for example the equator) have excess heat in the air, causing it to rise in the atmosphere. As that air rises, it begins to lose some of its heat energy until it begins to sink in areas with less radiation and cooler temperatures. This movement of air in convection currents forms predictable winds, leading to constant surface sea currents at different latitudes (Figure 7.10).

In the Northern Hemisphere, these currents tend to have a clockwise spiral, while in the Southern Hemisphere they have a counter-clockwise spiral. These spiral patterns are caused by the Coriolis Effect. The Coriolis Effect is a result of the Earth's rotation. As an object moves across the rotating Earth, the object swerves slightly to the left or right rather than travelling in a straight line. So, as wind blows the seawater across the ocean surface the rotation of the Earth actually deflects the water at a 45° angle. That is why wind and currents have spiral patterns away from the equator in both hemispheres (Figure 7.11).

Deep currents

Deep-water currents (thermohaline circulation) are driven by differences in density caused by salinity and temperature. These currents happen along the ocean floor and cannot be detected by satellite imagery the way surface currents can. The movement of these currents over the planet is called the 'global conveyor belt' (Figure 7.12). These slow-moving currents carry a huge volume of water: more than 100 times the flow of the

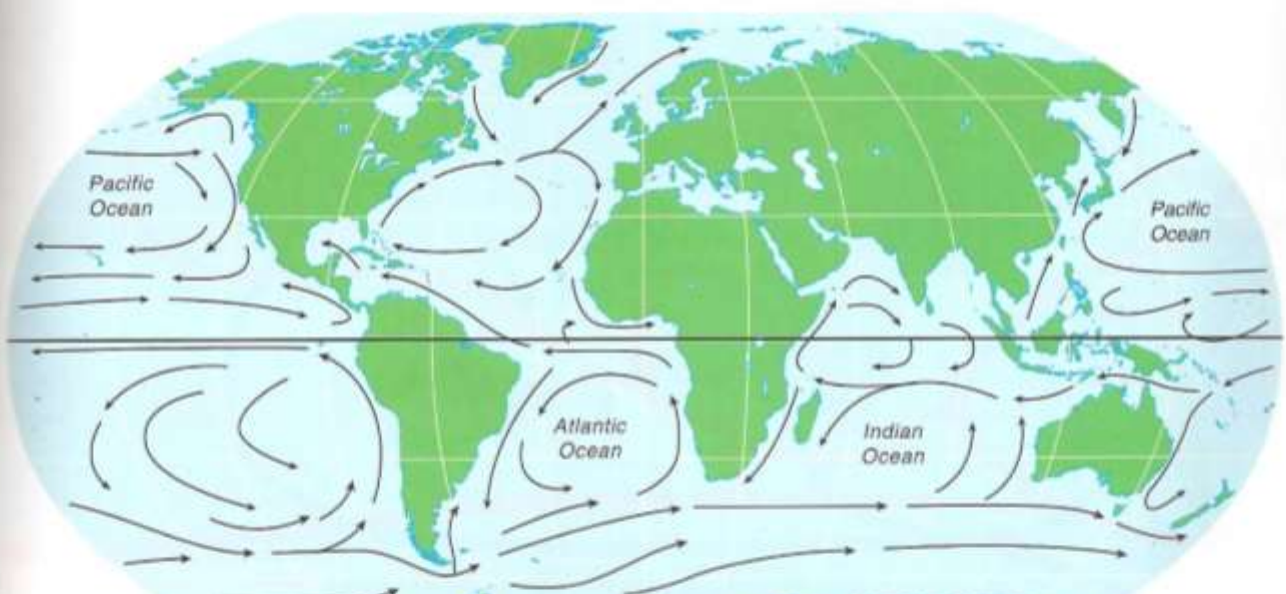


Figure 7.10. Surface currents in the ocean.

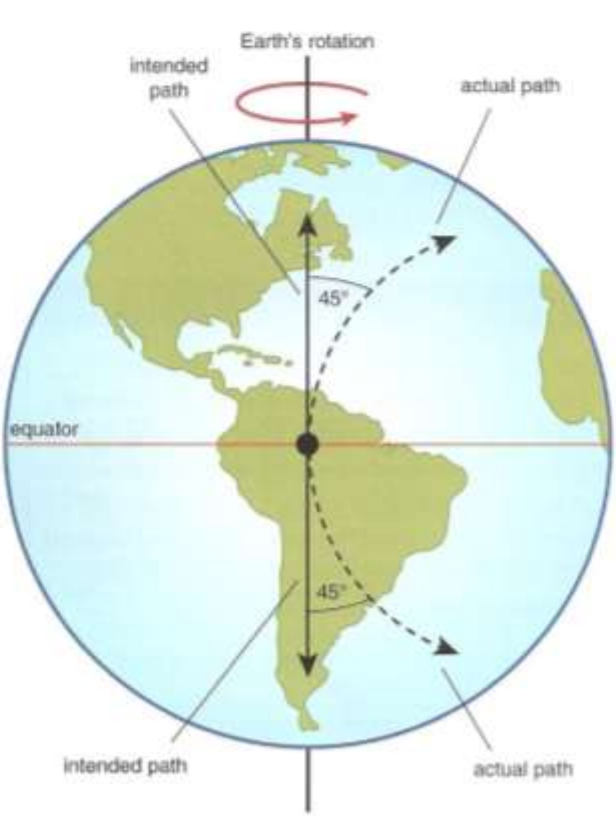


Figure 7.11. Diagram of the Coriolis Effect on objects moving over the Earth's surface.

Amazon River. The global conveyor belt starts at the North Pole when the cold water freezes into sea ice, leaving behind the salts, which do not freeze. This now denser water downwells, causing a mixing of the water column, until it reaches the bottom of the ocean. The water then begins moving south through the Atlantic Ocean towards Antarctica. In Antarctica, it picks up more cold water and then splits. One part of the belt goes towards the Indian Ocean and the other towards the Pacific Ocean. In the Indian Ocean, this cold water moves northwards towards the equator, bringing nutrients to the eastern African coasts. The water warms as it moves towards the equator, so it begins to rise to the surface. When the water cannot rise any longer, it loops back through the south Indian Ocean as a warm surface current.

The cold water in the Pacific Ocean moves through the equator toward the northern Pacific. As this water warms it also rises, becoming a warm surface current along the western coast of North America. This warm current then wraps around the northern coast of Australia and reconnects with the Indian Ocean portion of the global conveyor belt. Together, these warm currents flow through the Atlantic Ocean back towards the North Pole, where the entire process will begin again.

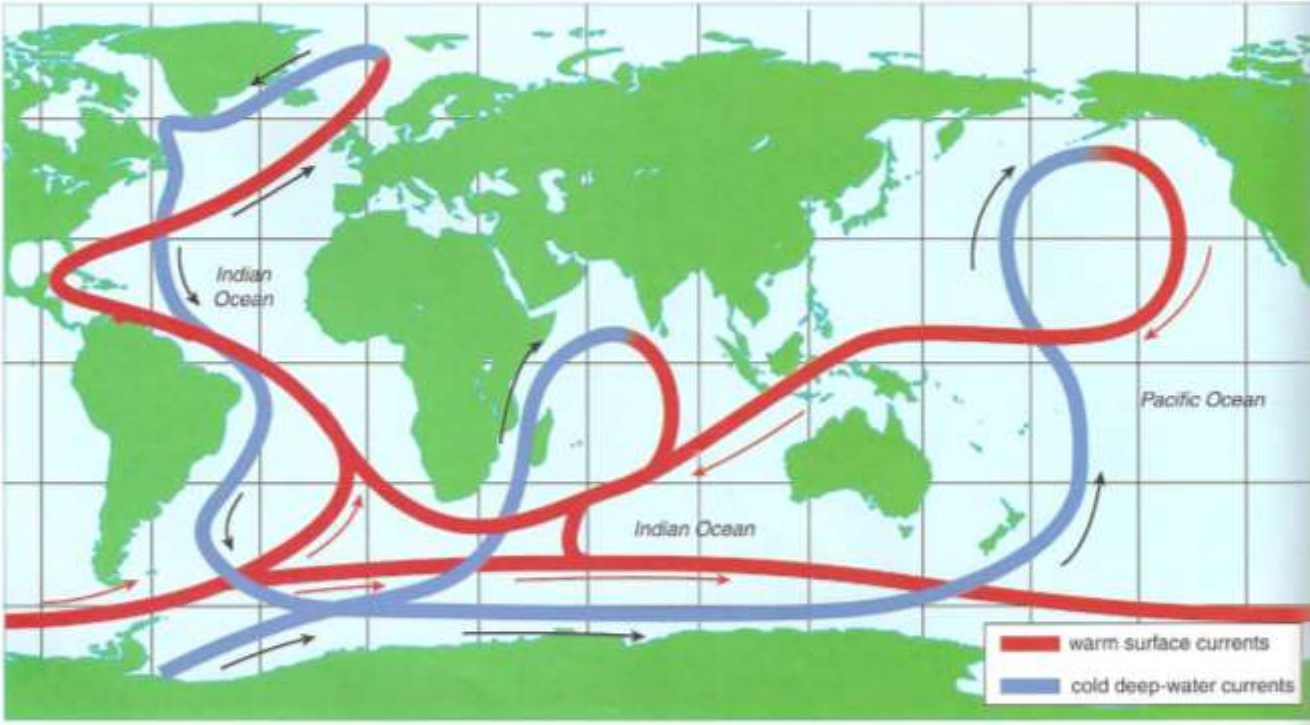


Figure 7.12. Thermohaline circulation (the global conveyor belt) showing the distribution of heat worldwide.

KEY TERM

Upwelling: the movement of cold, nutrient-rich water from deep in the ocean to the surface

Upwelling

Upwelling is the movement of cold, nutrient-rich water from the seabed vertically to the ocean's surface. Upwelling can be caused by winds forcing the warmer surface water away from the coastline and creating a low pressure zone that brings colder water to the surface (Figure 7.13). Upwelling can also be caused by the topography of the seabed. A mid-ocean ridge, or sea mount, can deflect a cold water current upwards causing upwelling. This movement of nutrient-rich water upwards acts as fertiliser for surface waters, increasing the productivity of producers in the area.

An excess of producers and biomass then increases the biomass of consumers, making areas with upwelling very healthy ecosystems with a lot of biological productivity.

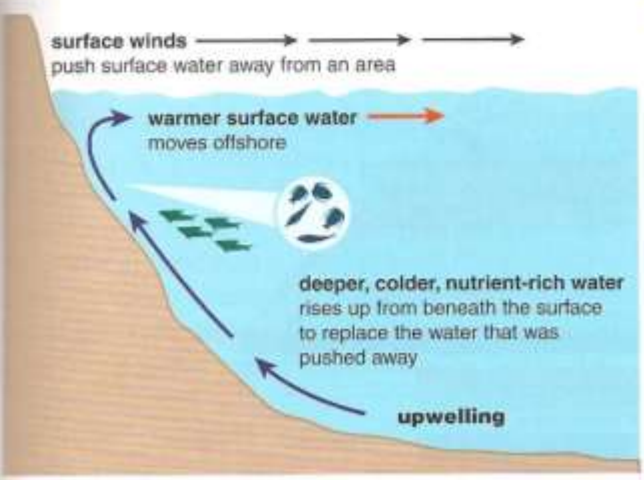


Figure 7.13. The process of upwelling as a result of surface winds.

SELF-ASSESSMENT QUESTIONS

5 If you owned a seaside home and a bad storm brought heavy winds and high surf to your coastline, would you prefer it to be during a new moon or a quarter moon? Why?

6 Compare and contrast a current and a tide.

El Niño Southern Oscillation

Normal conditions

Under normal conditions (Figure 7.14), currents flowing north along the west coast of South America bring cold, nutrient-rich water towards the equator. This flow of water is part of the global conveyor belt. As strong south-westerly winds blow water away from the coast of South America, the cold, nutrient-rich water moves toward the surface, causing upwelling and high levels of productivity off equatorial South America. This leads to large numbers of small fish (for example anchovies and sardines), which support a substantial fishery industry, along with many species of sea birds and large marine consumers.

However, on the other side of the Pacific, these westerly winds push large amounts of warm water towards Australia and Asia. The water levels in the western Pacific Ocean are about 0.5 m higher than those found in the eastern Pacific Ocean. The warm water that has been pushed west evaporates, creating massive storm clouds and bringing large amounts of much-needed rain to Australia and Asia, while keeping the eastern Pacific fairly dry.

KEY TERM

El Niño: a warm current that develops off the coast of Ecuador around December, which can cause widespread death within local food chains

El Niño conditions

Every 3–5 years (sometimes as long as 7 years), the weather pattern in the Pacific Ocean changes. The change is referred to as **El Niño** or the El Niño Southern Oscillation (ENSO). The prevailing trade winds that normally blow from east to west along the equator stop blowing in their normal pattern. Instead these winds reduce, preventing warm water and moist air from moving to the west (Figure 7.15). The warm water builds up along the coast of South America, stopping the upwelling that usually occurs when the Humboldt Current brings cold water to the surface. Indonesia and Australia experience drought conditions, because of a reduction in rainfall, while Peru and the eastern Pacific experience increased rainfall.

Without the upwelling off the South American coast, there is no fresh supply of nutrients or colder water to reduce surface temperatures. As a result, many cold-water species die and primary productivity goes into a steep decline due to lack of nutrients. The lack of producers impacts upon every other level of the local food webs.

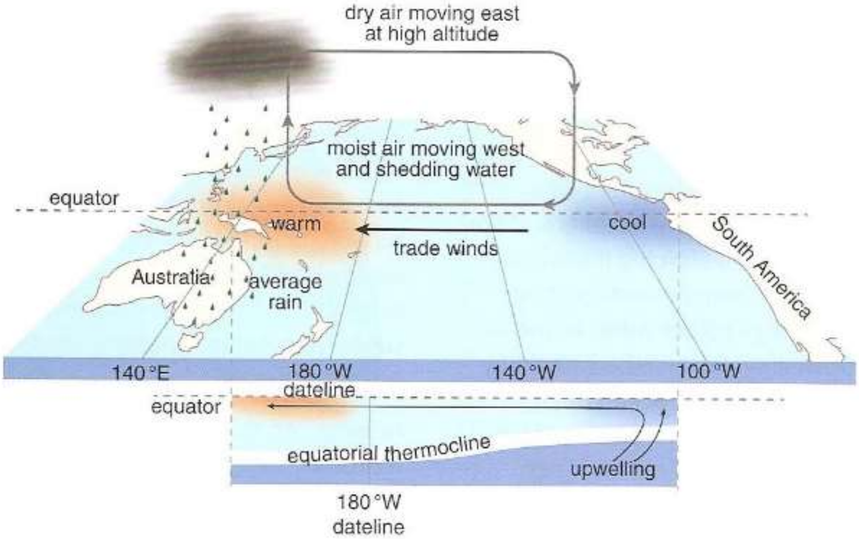


Figure 7.14. Normal weather conditions in the equatorial Pacific Ocean.

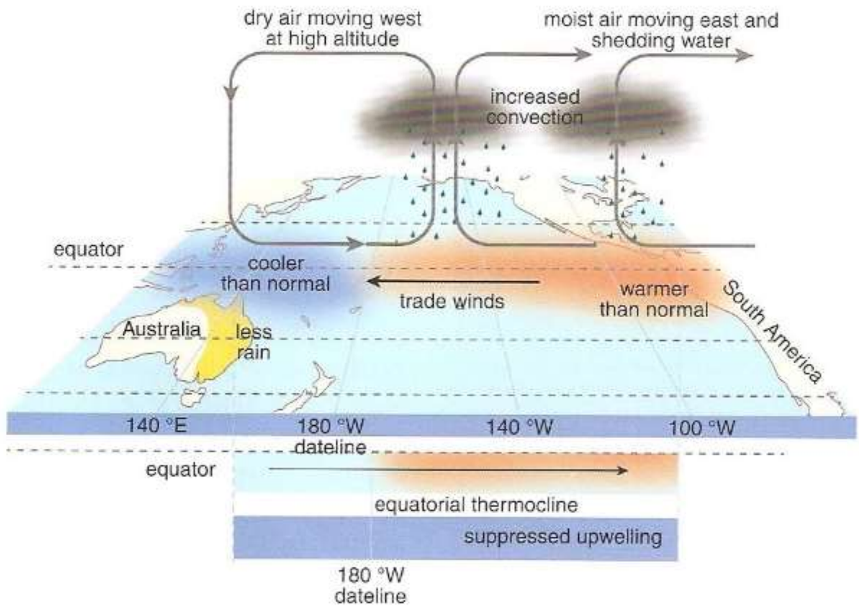


Figure 7.15. El Niño conditions in the equatorial Pacific Ocean.

This causes both the ecosystems and the fishing industries to fail during these times.

El Niño is a naturally occurring phenomenon, but its exact cause is not known. A problem with determining the cause is that not all El Niño years begin or progress in the same way. There has been some speculation that climate change is an exacerbating factor in the increasing occurrence of El Niño conditions, but it is unlikely that this is the only factor involved.

Major El Niño events

Scientists use the Oceanic Niño Index (ONI) to identify El Niño events. The ONI tracks average sea-surface temperature in the equatorial Pacific region in 3-month increments. If there are five consecutive overlapping 3-month periods with sea-surface temperatures at or more than +0.5 °C above average temperatures, they consider it to be an El Niño event. There have been a few 'very strong' El Niño events in the past few decades according to the ONI.

- 1982–83: sea-surface temperatures rose to 2.1 °C above average and caused massive flooding along the eastern Pacific basin.
- 1997–98: the strongest El Niño event recorded so far, sea-surface temperatures rose 2.3 °C above the average temperature.
- 2015–16: scientists believe this event may equal or surpass the 1997–98 event, sea-surface temperatures had risen 2.3 °C above the average sea-surface temperature by May 2016.

Monsoons

Asia is widely considered to be the largest continent. Because of its size, Asia is home to a multitude of biomes and climate conditions. From the warm, wet rainforest in south-east Asia to the cold, dry deserts in northern Asia, nearly every climate can be found in this large region. One feature of the climate in southern Asia is the **monsoon**. Monsoons are seasonal winds that come from the Indian Ocean.

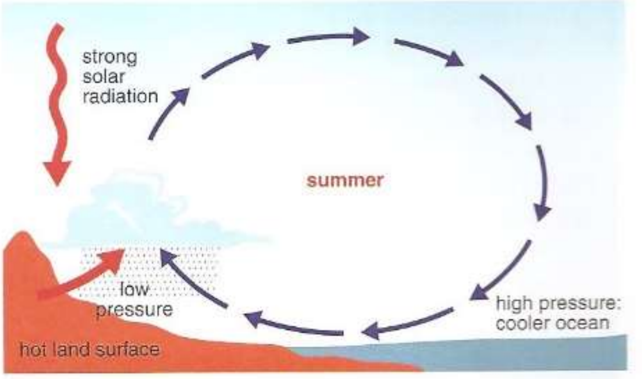
KEY TERM

Monsoon: seasonal winds in India that blow from the south-west during the summer and the north-east during the winter

Monsoons are created by the uneven heat capacity of land and sea. During the summer months (May–August), the land absorbs solar radiation much faster than the Indian Ocean, creating a large temperature difference (Figure 7.16). The air over the landmass is then heated as the warmth from the land is re-radiated to the atmosphere. This air rises as its density decreases and draws in the denser, warm, humid air that was lying over the Indian Ocean. The wind created by this vacuum blows from the south-west and brings thunderstorms and torrential rain. Summer monsoons account for 80% of the yearly rainfall in India, causing flooding while also supporting their primary agricultural crops like rice and cotton.

In September, the temperature difference between the land and ocean begins to even out, reducing the winds. By October, and through the winter months, the oceans hold more heat than the landmass. This means the saturated air over the ocean begins to rise and become less dense. In order to fill the vacuum left by this rising air, cool, dry air from the landmass begins to blow toward the ocean from the north-east. The wind blowing from the north-east is called the 'post-monsoon'. All the moisture evaporated from the ocean remains over the ocean, where rainstorms release the water back into the ocean. Meanwhile the Asian landmass is left with drought conditions until the summer monsoons return.

(a)



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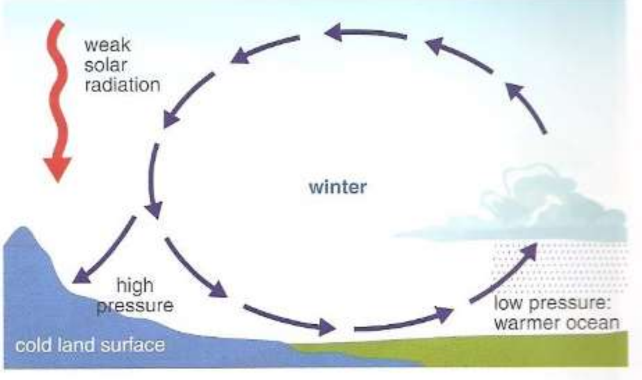


Figure 7.16. Monsoon winds during summer and winter.

Tropical cyclones

In the Indian and south Pacific oceans, large storm systems with wide, low-pressure centres, strong winds (over 120 km h^{-1}) and heavy rains are called **tropical cyclones**. Elsewhere, storms with the same physical structure and method of formation have different names. In the North Atlantic and north-east Pacific, these storms are called **hurricanes**. In the north-west Pacific, they are called **typhoons**. In this book, these storms are all called tropical cyclones.

KEY TERMS

Tropical cyclone: a localised, intense low-pressure wind system that forms over tropical oceans with strong winds

Hurricane: a tropical cyclone with wind speeds of more than 120 km h^{-1}, generally applied to those occurring in the Atlantic Ocean and northern Pacific Ocean

Typhoon: a tropical cyclone in the Indian Ocean or western Pacific Ocean

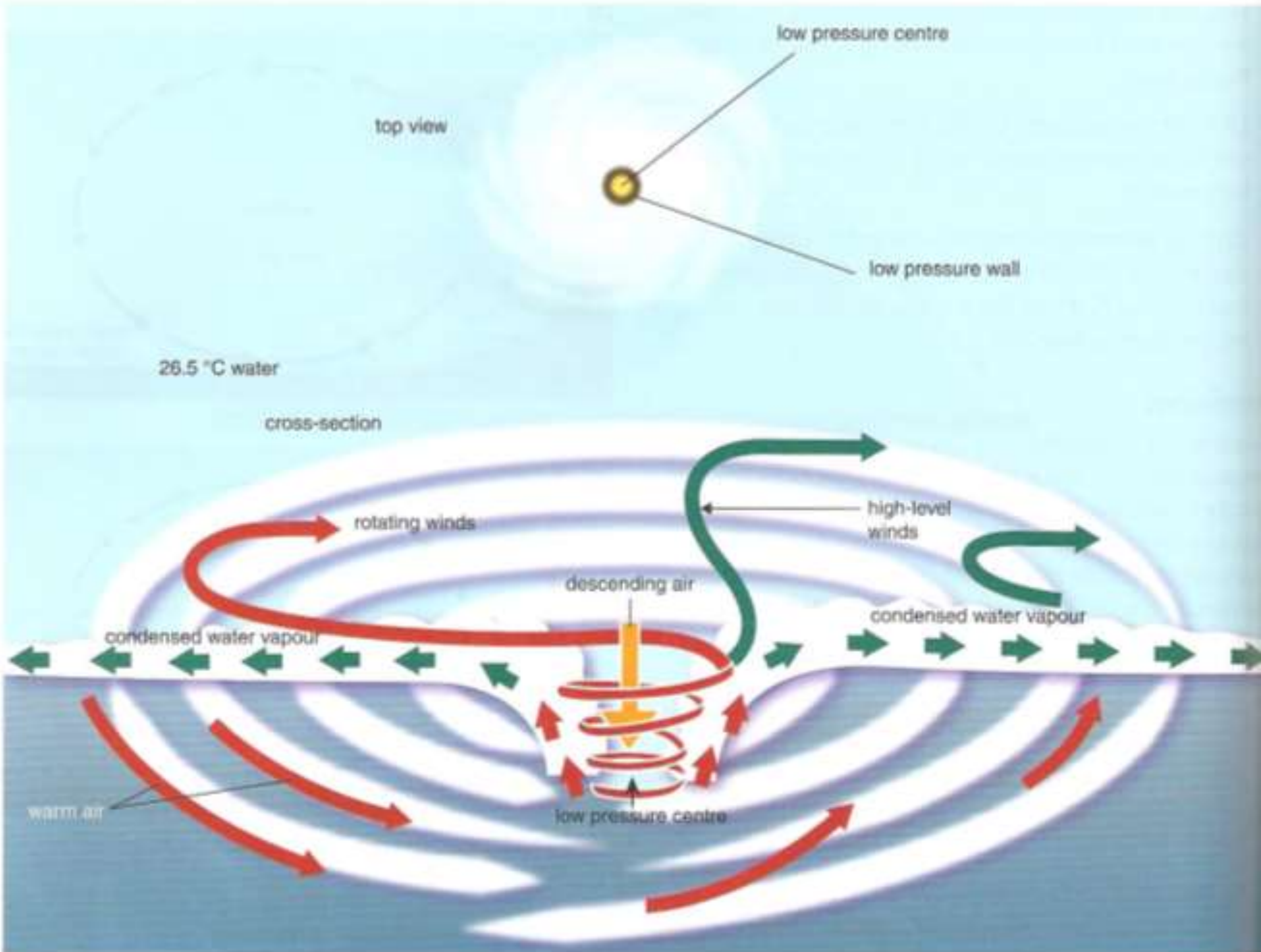


Figure 7.17. Formation of a tropical cyclone.

Formation

Everywhere in the world, these storms always form under the same conditions. For a tropical cyclone to form, there must be a large body of warm water (temperatures higher than 26.5 °C). As the air over this warm water heats up, it begins to rise because of its decreasing density, even as it is filled with water vapour through evaporation. This rising air creates a low-pressure area, often called 'the eye', over the water, drawing in cooler air. The cooler air begins to create winds as it too warms and rises, drawing evaporated water vapour with it. Once risen, the water vapour in the warm air **condenses** and releases large amounts of stored energy in the form of heat (**latent heat**). This heat energy works to warm even greater amounts of air, causing even more evaporation and drawing in larger winds and fuelling the development of a tropical cyclone (Figure 7.17).

KEY TERMS

Condensation (condense): when water changes from vapour to liquid, the energy needed to maintain the vapour state is released into the atmosphere

Latent heat: the quantity of heat gained or lost per unit of mass as a substance undergoes a change of state (for example vapour to liquid)

This system of warming and rising begins to spin becaus of the rotation of the Earth and the Coriolis Effect. As th air rises, it does so at a 45° angle from the winds coming into the low-pressure zone. In the Northern Hemisphere, cyclones rotate counter-clockwise; in the Southern Hemisphere, they rotate in a clockwise direction.

This spinning system of high winds and latent heat is no stationary. As the prevailing winds blow the warm wate

...rents that feed these storms, they also push the storms ...e same direction. In the northern Atlantic, for example, ...ricanes are pushed by the north-east trade winds from ...e western coast of Africa across the Atlantic towards the ...f of Mexico. Scientists use computer-based models to ...edict the path or 'track' of the storm.

...pacts on coastal communities

...e high winds and torrential rains of tropical cyclones ...n be incredibly dangerous and destructive to the ...mmunities – both human and ecological – within their ...th. The wind during a tropical cyclone often blows ...adily over 90 km h^{-1} and can gust up to 280 km h^{-1}. Such ...gh winds destroy coastal properties and cause incredible ...mage to the built environment. Huge waves erode ...orelines and damage moored boats.

...orm surges (drastic, unpredictable increases in sea-level) ...d heavy rainfall often accompany tropical cyclones. ...tween the storm surges and increased precipitation, ...oding is inevitable in low-lying coastal areas. These floods ...e capable of causing many drownings within the storm area.

Ecologically speaking, these storms have both positive and negative impacts. The storms and accompanying storm surges lead to erosion, loss of shoreline and loss of coral reefs (see Chapter 5). However, the heavy rainfall may happen in places with a dry, arid climate. The influx of rain helps the people and organisms in the area survive. Additionally, storm surges carry many nutrients to coastal communities. This means that the reservoir of nutrients stored in the coastal waters is refilled. Producers in the affected area are no longer limited by a scarcity of nutrients and overall productivity is increased.

SELF-ASSESSMENT QUESTIONS

7 Describe how wind patterns are related to the El Niño Southern Oscillation.

8 How could El Niño lead to increased numbers of tropical cyclones?

Summary

- Chemical and physical oceanography share a connection that allows life to survive on this planet.
- Upwelling is caused by physical factors (for example temperature differences) that can change the chemical make-up of coastal ecosystems by bringing in fresh nutrients.
- These nutrients increase productivity in the area and support incredibly biodiverse food webs and major fishing industries.
- The average salinity of the ocean is 35‰.
- The salinity and gaseous dissolution of seawater vary depending on environmental and physical conditions such as temperature, density and pressure.
- Chemicals and gases enter the ocean through dissolution, run-off and volcanic eruptions.
- Layers form in the ocean based on temperature and salinity differences, creating varying degrees of density. The denser a layer is, the lower in the water column it will be.
- As temperature increases, dissolved oxygen decreases, except where there are a large number of producers photosynthesising.
- Spring tides have the greatest tidal range and happen when the Moon, Sun and Earth are in a straight line.
- Neap tides have the smallest tidal range and happen when the Moon and Sun are at right angles to each other.
- The uneven heating of the Earth creates winds that blow the water of the ocean, creating currents.
- The Earth rotates, forcing the winds and currents to move at a 45° angle (the Coriolis Effect), creating a circular pattern.
- El Niño happens when there is less cool water and therefore warmer conditions in the eastern Pacific, so upwelling off the western South American coast is suppressed. Cooler than normal conditions prevail in the western Pacific.
- Monsoons are seasonal winds that bring flooding in the summer and drought in the winter.
- Tropical cyclones form over warm water in areas with a low-pressure centre and bring strong winds and heavy rains.
- Tropical cyclones are also known as hurricanes and typhoons.

Opdracht bij les 2.2

- Kiezen uit case studies: De Peruaanse ansjovis industrie / Stoppen de zeestromingen?

Les 2.2 - De Peruaanse ansjovis industrie

Ansjovis zijn kleine foerageervissen die gebonden worden in de open oceaan. Foerageervissen worden door andere roofdieren gebruikt als voedsel. Ansjovis zijn voornamelijk filteraars, water wordt door de mond naar binnen gezogen en zoöplankton wordt door de kieuwplaatjes eruit gefilterd. Foerageervissen zijn een belangrijke schakel in de voedselketen. Ze zijn voedsel voor:

- Grotere vissen zoals tonijn en zalm

- Zeezoogdieren zoals dolfijnen en walvissen

- Zeevogels zoals meeuwen en pelikanen

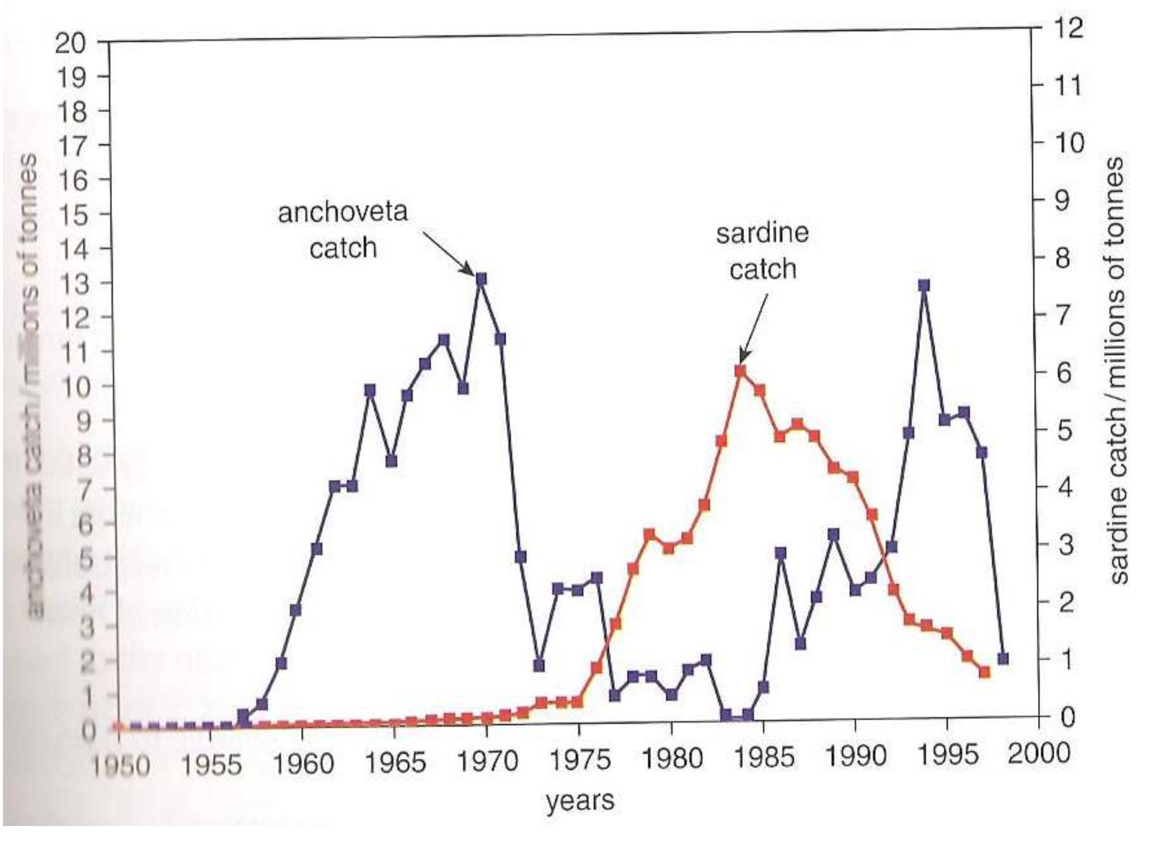
De Peruaanse ansjovis visserij is de grootste visserij op 1 soort ter wereld. Ansjoveta is een ansjovis soort die tot 3 jaar oud kan worden en 20 centimeter lang. In de jaren 60 waren de ansjoveta vangsten voor de kust van Peru meer dan 10 miljoen ton per jaar. In 1971 was dit 13,1 miljoen ton. In 1972 stortte de industrie in door overbevissing en El Niño.

El Niño is een verandering in de winden van de Grote Oceaan. Deze winden zorgen normaal gesproken voor het omhoog komen van koude voedingsstofrijke wateren, maar tijdens een El Niño jaar gebeurt dit niet. Na het instorten van de ansjovis populaties, richtte de industrie zich op het bevissen van sardines totdat de wateren genoeg afgekoeld waren en de ansjovis populaties zich herstelden.

1. Leg uit hoe een vermindering in voedingsstoffen in de bovenste laag van de oceaan kan leiden tot een vermindering in de aantallen van foerageervissen.

2. Ansjoveta voedt zich met grote zoöplankton, terwijl sardines zich voeden met fytoplankton. Waarom worden sardines minder beïnvloed door El Niño?

3. Bekijk de grafiek en geef nog twee jaren, behalve 1971, die El Niño jaren hadden kunnen zijn. Leg je antwoord uit.



Les 2.2 - Stoppen de zeestromingen?

Klimaatonderzoekster dr. Nanne Weber van het KNMI in De Bilt reageert verschrikt op de vraag of de mensheid zichzelf een ijstijd kan aandoen. Nee, dat niet, maar een kleine ijstijd, zoals de meest recente koude periode in de zeventiende eeuw, wil ze toch niet uitsluiten. Toen was het hier in onze regionen enkele decennia achtereen zo'n twee graden Celsius kouder dan gemiddeld. Tot voor kort was het idee dat veranderingen in het klimaat zich geleidelijk voltrekken. Maar dat blijkt niet altijd het geval. Uit onderzoek aan onder meer boorkernen uit de Groenlandse ijskap, waarin de klimaatgeschiedenis tot honderdduizenden jaren terug ligt opgeslagen, blijkt dat het af en toe binnen een korte tijd - enkele tientallen jaren - kouder of warmer kan worden.

Het meest bestudeerd is het Jonge Dryas - elf- tot twaalfduizend jaar geleden - een periode tijdens de overgang van de laatste ijstijd naar het Holoceen. Toen hebben zich enkele abrupte temperatuurschommelingen voorgedaan. Na een periode van extreme kou tijdens die laatste ijstijd, meer dan tien graden onder het huidige gemiddelde, werd het weer geleidelijk warmer. Die geleidelijke trend werd vervolgens onderbroken. In een tijdsbestek van hooguit enkele tientallen jaren werd het op Groenland gemiddeld zeven graden Celsius kouder, waarna het in korte tijd weer zeven graden Celsius warmer werd. Het klimaat sloeg daarna opnieuw de weg der geleidelijkheid in. Dergelijke snelle klimaatovergangen zijn niet alleen ontdekt in boorkernen uit de Groenlandse ijskap, maar ook in die van Antarctica en in het sediment van de Atlantische-Oceaanbodem. Weliswaar minder geprononceerd maar onmiskenbaar, aldus Weber.

Sinds die overgang naar het Holoceen zitten we volgens Weber in een saaie periode van de klimaatgeschiedenis. De gemiddelde temperatuur vertoont maar weinig variatie, hooguit twee graden Celsius. Zo beleefden we in de recente geschiedenis nog een kleine ijstijd, rond 1700, terwijl het in de Middeleeuwen hier wat warmer was. Of het zo saai blijft, is de vraag. Waarom zouden we in de komende eeuwen niet nog eens worden geconfronteerd met zo'n snelle klimaatwisseling? Sterker nog: werken we die niet zelf in de hand doordat de mensheid steeds grotere hoeveelheden broeikasgassen in de atmosfeer loost?

Een hypothese is dat die snelle klimaatschommelingen worden veroorzaakt door het stopzetten van een wereldomspannende watercirculatie in de oceanen waarmee onder meer warm en zout water uit de tropen langs de kust van Noord-Amerika naar het noorden wordt getransporteerd. De Warme Golfstroom voor de kust van Noord-Amerika, die het klimaat in West-Europa bepaalt, maakt onderdeel uit van die transportband op wereldschaal. Op theoretische gronden is te voorspellen dat die transportband stopt wanneer er een flinke plas zoet water vanuit het noorden de Noord-Atlantische Oceaan instroomt. Na verloop van tijd, zo'n duizend jaar, komt die transportband geleidelijk weer op gang. Uit computersimulaties blijkt dat de instroom van zo'n plas zoet water de transportband inderdaad kan stilzetten, aldus Weber. 'In het diepzeesediment zijn inmiddels al enige indicaties voor die hypothese gevonden.' Zo'n snelle toevoer van zoet water ontstaat ook wanneer het klimaat op het noordelijk halfrond natter wordt, omdat er meer neerslag valt.

Uit recente metingen blijkt dat de Golfstroom nu 30% minder sterk is dan in eerdere metingen. In het jaar 2300 wordt er een verzwakking van 74% verwacht.

1. Hoe kunnen onderzoekers het klimaat uit het verleden construeren met behulp van boorkernen?

2. Waar zou het zoete water vandaan kunnen komen dat de watercirculatie kan laten stoppen?

3. Op welke manier vertraagt of stopt de watercirculatie door toevoeging van zoet water bij de Noordpool?

4. Welk effect zou je in Europa verwachten door het stoppen van de watercirculatie? Leg je antwoord uit.

5. Verklaar aan de hand van dit artikel waarom mensen het nu hebben over klimaatsverandering in plaats van het broeikaseffect.